Response of the Ostrich Eggshell to Non Destructive Impact

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Abstract

An experimental system was set up to generate the impact force, measure the response wave signal, and analyse the frequency spectrum for physical properties detection of biological product. The dynamic resonance frequency of egg was obtained through the analysis of the dynamically measured frequency response of an egg excited by pendulum. The effects of excitation point, detected point and impact intensity on the dominant frequency were analysed.

Keywords

Egg; Physical Property; Dynamic; Resonance Frequency

Introduction

The strength of the Ostrich eggshells exhibits extremely high values (up to 700 N) among other avian eggs [5]. Eggshell strength is generally measured using either direct tests, such as non-destructive deformation [16] or destructive fracture force [1] of an egg under quasi static compression between 2 parallel plates, or indirect tests, such as the measurement of eggshell thickness [2, 3, 12, 14, 15] or specific gravity [9]. Many of these methods, however, are destructive, slow, or subjected to environmental influences and, hence, being regarded as unpractical. Coucke [7] presented a fast, objective, and non-destructive method for the determination of the eggshell strength, based on acoustic resonance analysis. This technique measures the resonant frequency (***RF***) of the egg and its damping ratio. Based on the (***RF***) and the egg weight, the dynamic shell stiffness (K_{dyn}) was defined. This technique can also be used to detect cracks in the eggshell [4, 7, 8] and has been widely applied to the study of chicken eggs. Its application to the study of the mechanical behaviour of the Ostrich eggs should be very important namely owning to the non destructive nature of this procedure. Ostrich eggs are high-priced in order to perform some more detail destructive studies.

In this research, egg was excited by the impact of an aluminium cylinder on the sharp side or the hip side or the equator, and the response signals (eggshell surface displacements) were detected by laser vibrometer at different points on the eggshell surface. The response wave signals were then transformed from time to frequency domain and the frequency spectrum was analysed. The specific objectives of the research were to analyse the response time signals and frequency signals of eggs. The geometry of the Ostrich eggshell has been studied as well.

Material and Experimental Technique

A. Egg

The Ostrich (*Struthio camelus*) egg has been used with weighs 1.495 kg, and the mean length and width were 148 and 120 mm, respectively. The mean weight of albumen reaches 900 g, with a 310 g yolk and a 280 g voided shell. The average shell thickness was 1.21 mm. The shape of an egg can be described with its index being the percentage ratio of width to length. This egg shape parameter is widely used for the egg geometry description. Its use is sufficient for the description on the eggshell behaviour under quasi static loading [10]. The solution of impact problems needs a more detail description of the egg shape.

The more precise description of the egg shape has been obtained using the digital photos of the egg. The image analysis performed using of the MATLAB software has been used for the evaluation of the coordinates x_i and y_i on the egg contour. Instead of Cartesian coordinates, the shape of the eggshell counter can be described using the polar coordinates r and φ:

$$x = r\cos\varphi \qquad y = r\sin\varphi.$$

The experimental points r_i, φ_i have been fitted by the Fourier series

$$r = a_0 + \sum_{i=1}^{i=\infty} \left[a_i \cos(iw\varphi) + b_i \sin(iw\varphi) \right]. \tag{1}$$

The analysis of our data led to the conclusion that the first eight coefficients of the Fourier series – see Eq. (1) are quite sufficient for the egg's counter shape description, whose values are given in the Table 1. The correlation coefficient between measured and computed egg's profiles is 0.995.

From a mathematical description of an egg shape, it is possible to evaluate some other parameters like [13]:

The radius of the curvature R:

$$R = \frac{\left[\left(\frac{dx}{d\phi} \right)^2 + \left(\frac{dy}{d\phi} \right)^2 \right]^{\frac{3}{2}}}{\left| \frac{dx}{d\phi} \frac{d^2 y}{d\phi^2} - \frac{dy}{d\phi} \frac{d^2 x}{d\phi^2} \right|}. \tag{2}$$

The volume V and surface S provided the egg can be assumed to be a solid of revolution

$$V = \pi \int_{\phi_1}^{\phi_2} r^2(\phi) \sin^2 \phi \frac{dx(\phi)}{d\phi} d\phi,$$

$$S = 2\pi \int_0^{\pi} r \sin \phi \sqrt{\left(\frac{dx}{d\phi} \right)^2 + \left(\frac{dy}{d\phi} \right)^2} d\phi, \tag{3}$$

the area A of the egg normal projection and the long circumference length, l:

$$A = \frac{1}{2} \oint r^2 d\varphi \qquad l = \oint ds = \oint r d\varphi. \tag{4}$$

TABLE 1 COEEFICIENTS OF THE FOURIER SERIES

a_0	**a_1**	**a_2**
63.09	16.35	5.933
a_3	**a_4**	**a_5**
1.545	0.3175	0.1825
a_6	**a_7**	**a_8**
0.06055	0.005896	-0.01131
b_1	b_2	b_3
-21.74	-2.493	-2.316
b_4	**b_5**	**b_6**
-0.3627	-0.3004	-0.1086
b_7	**b_8**	**w**
-0.1128	0.006658	1

These parameters given by the Eqs. 3 and 4 are in the Table 2.

TABLE 2 PARAMETERS GIVEN BY THE EQS. (3, 4)

S (mm²)	*V* (mm³)	*A* (mm²)	*l* (mm)
5.406.104	1.0565.106	1.375.104	461.4

In the Fig. 1 the egg's counter curve is shown. The agreement with experimental curve determined by digital photo is excellent.

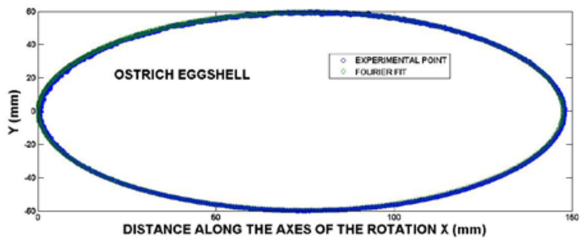

FIG. 1 EGG`S CONTOUR

The knowledge of the mathematical description of the curve describing the egg's contour can evaluate the radius of the curvature – see Eq. 2. An example of this radius is given in the Fig. 2.

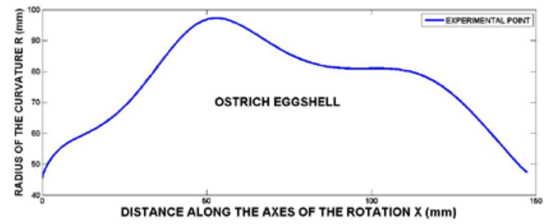

FIG. 2 RADIUS OF THE CURVATURE ALONG THE EGG`S SYMMETRY AXIS

B. Experimental Method

The non destructive impact has been performed using the equipment described in [11]. The schematic is shown in the Fig. 3.

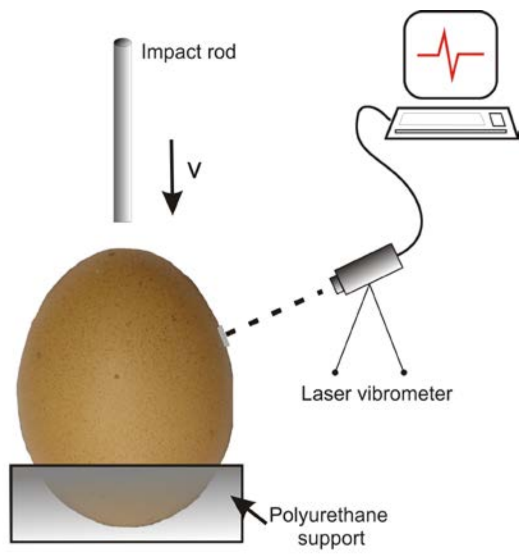

FIG. 3 SCHEMATIC OF THE IMPACT LOADING OF THE EGG

It consists of three major components: the egg support, the loading device and the response-measuring device.

1) The egg support is a cube made of soft polyurethane foam. The stiffness of this foam is significantly lower than the eggshell stiffness; therefore there is very little influence

of this foam on the dynamic behaviour of the egg.

2) A bar of the circular cross-section with strain gauges (semi conducting, 3mm in length) is used as a loading device. The bar is made from aluminium alloy with length 200mm, diameter 6mm. The bar is allowed to fall freely from a pre-selected height. The instrumentation of the bar by the strain gauges can record time history of the force at the area of bar-eggshell contact.

3) The response of the egg to the impact loading, described above, has been measured using the laser vibrometer. This device is capable to obtain the time history of the eggshell surface displacement.

The eggs have been impacted on the sharp end, on the blunt end, and on the equator. The height of the bar fall has been chosen as 50, 75, 100 and 125mm.

The displacement has been recorded at different points on the eggshell surface as shown in the Fig. 4.

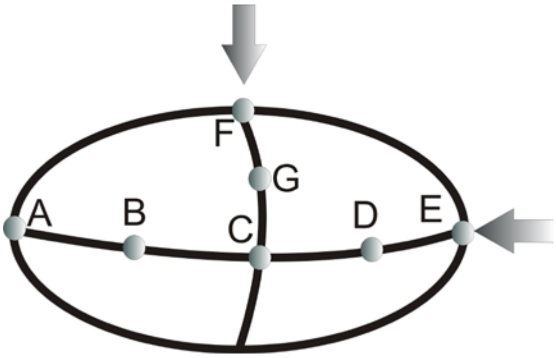

FIG. 4 POINTS OF IMPACT (A, E, F) AND POINTS OF THE SURFACE DISPLACEMENT DETECTION (AB = 65 MM, BC = 55 MM, CD = 55 MM, DE = 55 MM, FG = 55 MM, GC = 45 MM). POINT A REPRESENTS A BLUNT END OF THE EGG, RADIUS OF THE CURVATURE R1 = 47.48 MM, POINT B CORRESPONDS TO THE SHARP END OF THE EGG, R2 = 45.75 MM, AND POINT C POINT ON THE SURFACE AT THE MAXIMUM OF THE EGG WIDTH, R3= 97.22 MM.

The displacement has been measured in normal direction to the eggshell surface.

Results and Discussion

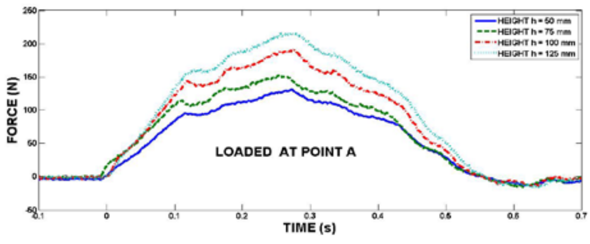

FIG. 5 EXPERIMENTAL RECORDS OF THE TIME HISTORY OF THE FORCE AT THE ROD IMPACT

In the Fig. 5, the experimental records of the force – time at the impact point A are displayed.

Each curve represents the average from 5 measurements. The course of the force, F, – time, t curves can be represented by four parameters:

- Maximum value of the force, F_m
- Time of the maximum force achieving, tI
- Time of the pulse F(t) duration, λ
- Impulse $I = \int_0^\lambda F(t)dt$.

The values of these parameters are given in the Table 3.

TABLE 3 PARAMETERS OF THE LOADING FORCE PULSES

Height (mm)	Point	F_{max} (N)	t_I (ms)	λ (ms)	IMPULSE (Ns)
50	A	130.6	0.273	0. 547	0.042830523
	E	150.7	0.27	0. 511	0.045435594
	F	81.0	0.167	0.335	0.017841614
75	A	152.7	0.264	0.564	0.050333989
	E	187.9	0.253	0.501	0.056465697
	F	107.5	0.137	0.347	0.023894173
100	A	190.2	0.277	0.553	0.062051796
	E	216.1	0.241	0.481	0.064813903
	F	126.6	0.138	0.352	0.028498947
125	A	215.4	0.275	0.56	0.071639358
	E	241.3	0.271	0.476	0.072307741
	F	135.1	0.141	0.352	0.030829254

The maximum value of the impact force increases with the height of the bar fall, i.e. with the impact velocity. For the same impact velocity, this maximum increases with the curvature of the eggshell contour as shown in the Fig. 6.

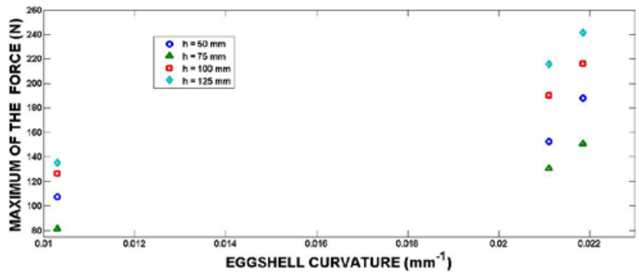

FIG. 6 MAXIMUM OF THE LOADING FORCE

In the Fig. 7, the time histories of the surface displacement around the meridian are shown. This displacement corresponds to the surface wave propagation. It is obvious that there is a significant damping of this wave. The surface displacement increases with the intensity of the impact. An example of this effect is shown in the Fig. 8.

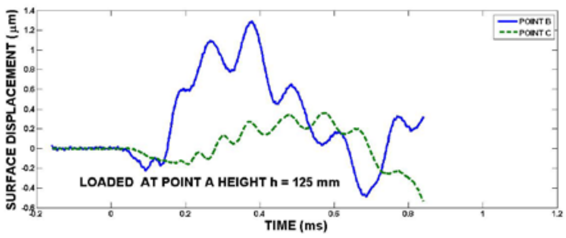

FIG. 7 SURFACE DISPLACEMENT OF THE EGGSHELL

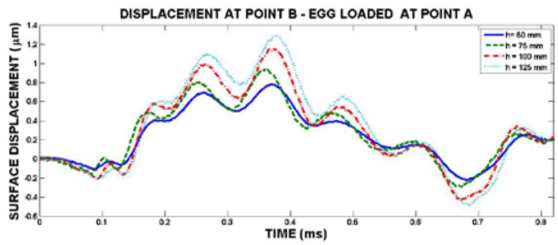

FIG. 8 THE INFLUENCE OF THE IMPACT INTENSITY ON THE SURFACE DISPLACEMENT

The time history of the surface displacement is also influenced by the point of the bar impact. This effect is illustrated in the Fig. 9.

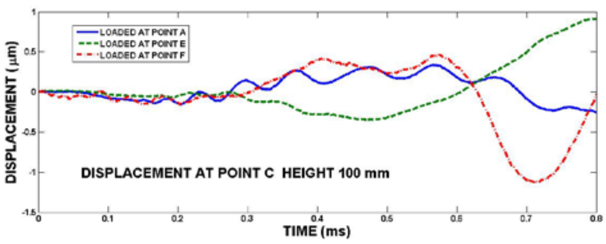

FIG. 9 SURFACE DISPLACEMENT AT THE POINT C (POINT ON THE EQUATOR)

Generally the surface displacement of the egg to the bar impact dependent is significantly affected by the position of excitation point, detected point and impact intensity. This is valid for the eggshell response in the time domain.

In the next step MATLAB software was used to transform the response from time to frequency domain by means of fast Fourier transform (FFT), as demonstrated in Fig. 10.

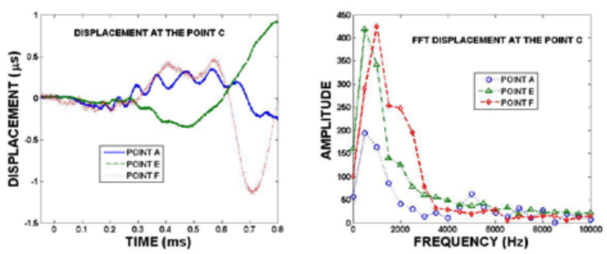

FIG. 10 TYPICAL TIME SIGNAL AND FREQUENCY SIGNAL AT THE DIFFERENT EXCITATION POINTS. LEFT PART – TIME SIGNAL. RIGHT PART – FREQUENCY SIGNAL OF RESPONSE

The frequency response function exhibits a maximum at the frequency which is denoted as resonant or dominant frequency [17]. Its value, ωmax is then used to calculate the dynamic eggshell stiffness (kdyn). Modelling the egg as a mass-spring system, the dynamic stiffness kdyn is given as [7]:

$$k_{dyn} = m\omega_{\max}^{2}, \qquad (5)$$

where m is the egg mass. In the Table 4 the values of the dominant frequencies determined at the point C are given.

TABLE 4 VALUES OF THE DOMINANT FREQUENCY

Height (mm)	Point of excitation	ω_{max} (s^{-1})
50	A	500
	E	500
	F	500
75	A	500
	E	500
	F	1000
100	A	1000
	E	500
	F	500
125	A	500
	E	500
	F	500

The dominant frequency is insignificantly affected by excitation point and excitation velocity (height of the fall). There are only two exceptions which should be verified by the next experiments. It is also independent on the surface curvature. The influence of the detection point position is also negligible, which means that this quantity can be considered as a measure of the eggshell rigidity following from its material properties. Very similar results have been achieved in [17] for the chicken eggs.

Conclusions

The response of the eggshell to non destructive impact has been studied. It has been found that the maximum of the stress pulse is dependent on the height of the bar fall (i.e. on the impact velocity) and on the surface curvature. The surface stress wave is highly attenuated during its propagation. The surface displacement of the eggshell is significantly affected by the position of excitation point, point of detection and impact intensity.

The egg dynamic resonance frequency detected, was obtained through the analysis of the dynamically measured frequency response of an excited ostrich egg. The response of the egg was very similar to that reported for the chicken eggs. The excitation point, the

detected point and excitation velocity probably did not significantly affect the dominant frequency. This hypothesis must be verified by some more extensive experiments, which means that there is a chance to predict the mechanical behaviour of the eggshell on the basis of non destructive impact test.

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